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Multimachine Power System Stabilizer based on Optimal Fuzzy PID with Genetic Algorithm Tuning

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Abstract: This paper presented PSS (Power system stabilizer) design based on Genetic Algorithm - Fuzzy PID (Proportional Integral and derivative) or GAFPID. GAFPID based PSS design is considered for multimachine power system. The main motivation for this design is to stabilize or to control low-frequency oscillation and terminal voltage of power systems. Genetic Algorithm (GA) is employed for the optimization of the parameter of stabilizer. By minimizing an objective function in which the oscillatory speed deviation of the generator, small signal and large signal performance of the system is improved. The effectiveness of the proposed PSS in increasing the damping of system electromechanical oscillation is demonstrated in a simple two-area power system.

Key words: Fuzzy PID, genetic algorithm, power system stabilizer.

1. Introduction

Low-frequency oscillations are a common problem in large power systems. PSS (power system stabilizer) is one of alternative solutions. PSS can provide auxiliary control signal to the excitation system and/or the speed governor system of the electric generating unit. This can also damp oscillation and improve its dynamic performance.

Most PSSs employ the classical linear control theory. PSS design approach is based on a linear model in fixed configuration of the power system. This results in fixed-parameter of PSS. It is called a conventional PSS (CPSS) and widely used in power systems to damp out small oscillations [1-4].

Power system stabilizers based on adaptive control, artificial neural networks, and fuzzy logic are being developed. Each of these control techniques possesses unique feature and strength. Fuzzy logic-based PSS shows great potential in increasing the damping of generator oscillations, especially when made adaptive [5-7].

In the past some researchers have taken initiatives to investigate the design fuzzy PID [8-9]. Different approaches have been proposed to design of fuzzy PID [10-13]. The main problem of optimal fuzzy PID stabilizer design is the tuning of fuzzy PID parameters. The tuning of a fuzzy PID for improved system dynamic like power system is complex task as compared with the tuning procedures of conventional stabilizer [14].

In this papers, an optimal fuzzy PID stabilizer is developed, which uses the post-disturbance value of the speed deviation as the input. Then this signal is used as the input of fuzzy PID stabilizer. To reach optimal speed deviation, the fuzzy PID stabilizer is tuned by GA.

2. Fuzzy PID Stabilizer

The basic principles underlying the design of the proposed fuzzy PID stabilizer can be illustrated by the block diagram in Fig.1, in which a synchronous gener-

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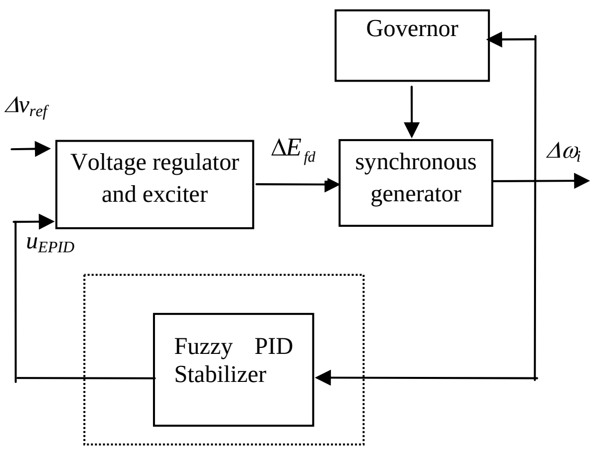

Fig. 1 Structure of the study system.

ator i with a static exciter is equipped with a fuzzy PID controller whose gain settings are tuned by PSO. The generator speed deviation Δω is as the input signal of the proposed stabilizer.

In this section, first we briefly describe the mathematical principle for the fuzzy PID stabilizer design, including the fuzzification, rule-base and defuzzification. Then fuzzy PID stabilizer is developed. The fuzzy PID stabilizer is normally a fuzzy PID controller with different input. Details in the design of the fuzzy PID controller can be found in Malki et al. [8, 9], Tang et al. [12] and Lu et al [13].

The general continuous-time PID stabilizer or PID controller has the expression

$$u_E(t) = K_p \Delta\omega(t) + K_I \int \Delta\omega(t)dt + K_D \frac{d\Delta\omega}{dt} \quad (1)$$

Where $\Delta\omega$ is speed deviation of machine and K_P, K_I, and K_D are PID controller parameters.

This is first converted into the frequency domain to get

$$u_E(s) = (K_P + \frac{K_I}{s} + sK_D)\Delta\omega(s) \quad (2)$$

2.1. Derivation of the Fuzzy PD Stabilizer

The output of the conventional analog PD stabilizer in the frequency-domain is given by

$$u_{EPD} = (K_P^c + sK_D^c)\Delta\omega(s) \quad (3)$$

Where K_P^c and K_D^c are the conventional proportional and derivative gains, respectively, and *Δω(s)* is the speed deviation signal. This equation can be transformed into the discrete version by applying the bilinear transformation

$$s = \frac{2}{T}\left[\frac{z-1}{z+1}\right]$$

Where is T the sampling period, which results in

$$u_{EPD}(z) = (K_P^c + K_D^c \frac{T}{2}\frac{1-z^{-1}}{1+z^{-1}})\Delta\omega(z) \quad (4)$$

Letting $K_P = K_p^c$ and $K_D = 2K_D^c / T$, and then taking the inverse z-transform, we have

$$\begin{aligned} & u_{EPD}(nT) + u_{EPD}(nT-T) \\ &= K_P[\Delta\omega(nT) + \Delta\omega(nT-T)] \\ &\quad + K_D[\Delta\omega(nT) - \Delta\omega(nT-T)] \end{aligned} \quad (5)$$

Further dividing Eq. (1) by T, and using to mean from now on Eq. (4), we obtain

$$u_{EPD}(n) = K_P d(n) + K_D r(n) \quad (6)$$

Where

$$u_{EPD}(n) = \frac{u_{PD}(n) + u_{PD}(n-1)}{T}$$

$$r(n) = \frac{\Delta\omega(n) - \Delta\omega(n-1)}{T}$$

$$d(n) = \frac{\Delta\omega(n) + \Delta\omega(n-1)}{T}$$

We can then rewrite (3) as

$$u_{EPD}(n) = -u_{EPD}(n-1) + T\Delta u_{EPD}(n) \quad (7)$$

Replacing the term $T\Delta u_{PD}(n)$ by a fuzzy control action gain, we finally arrive at

$$u_{EPD}(n) = -u_{EPD}(n-1) + K_{uPD}\Delta u_{EPD}(n) \quad (8)$$

Where K_{uPD} is a fuzzy PD control gain.

2.2 Derivation of the Fuzzy I Stabilizer

The output of the conventional analog I stabilizer in the frequency-domain is given by

$$u_{EI}(s) = \frac{K_I^c}{s}\Delta\omega(s) \quad (9)$$

Where K_I^c is the conventional integral control gain. Under the bilinear transformation, (9) becomes

$$u_{EI}(z) = \frac{T}{2}\frac{1-z^{-1}}{1+z^{-1}} K_i^c \Delta\omega(z) \quad (10)$$

So

$$u_{EI}(z) = K_I^c \frac{T}{2}\left(1 + \frac{2z^{-1}}{1-z^{-1}}\right)\Delta\omega(z) \qquad 11)$$

Then

$$u_{EI}(n) - u_{EI}(n-1) = \frac{K_I^c T}{2}[\Delta\omega(n) - \Delta\omega(n-1)] + K_I^c T\Delta\omega(n-1) \qquad (12)$$

$$\Delta u_{EI}(n) = K_I \Delta\omega(n-1) + Kr(n) \qquad (13)$$

Where $K_I = K_I^c$ and $K = (T/2)K_I^c$, with

$$\Delta u_I(n) = \frac{u_I(n) - u_I(n-1)}{T}$$

and

$$r(n) = \frac{\Delta\omega(n) - \Delta\omega(n-1)}{T}$$

Letting K_{uI} be a fuzzy control gain, as was similarly done for the fuzzy PD controller case discussed above, we arrive at

$$u_{EI}(n) = u_{EI}(n-1) + K_{uI}\Delta u_{EI}(n) \qquad (14)$$

2.3 Combination of the Fuzzy PD+I stabilizer

Finally, the overall fuzzy PD+I control law can be obtained by algebraically summing the fuzzy PD control law Eq. (7) and fuzzy I control law Eq. (14) together. The result is

$$\begin{aligned} u_{EPID}(n) &= u_{EPD}(n) + u_{EI}(n) \\ &= -u_{EPD}(n-1) + K_{uPD}\Delta u_{EPD}(n) \\ &\quad + u_{EI}(n-1) + K_{uI}\Delta u_{EI}(n) \end{aligned} \qquad (15)$$

The overall fuzzy PID stabilizer is shown in Fig. 2, where the fuzzy PD and I stabilizers will be inserted into the configuration.

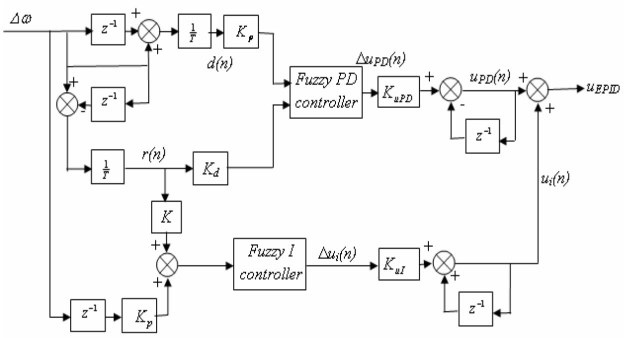

Fig. 2 The fuzzy PID stabilizer block diagram.

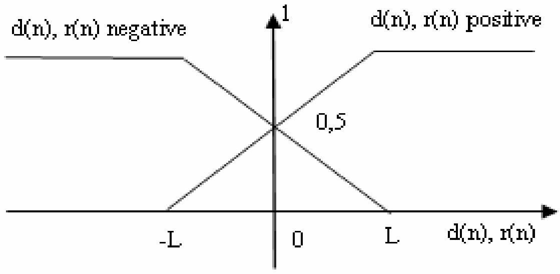

Fig. 3 The input membership functions for the PD and I component.

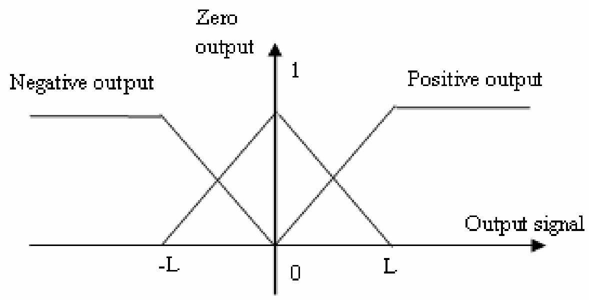

Fig. 4 The output membership functions for the PD and I component.

The input and output membership functions of the PD and I component are shown in Figs. 3 and 4, respectively. The rule-base and defuzzification of the fuzzy PID controller can be found in Malki *et al*. [8, 9], Tang *et al*. [12] and Lu *et al* [13].

3. Design of GAFPID Based PSS

The choice of suitable performance index is extremely important for the design of GAFPID based PSS. In this study, the PSS parameters are coded in a binary string and initial population is randomly generated. The proposed design algorithm employs GA to solve this optimization problem and search for the optimum set of PSS parameters.

A simple performance index that reflects small steady state error, small overshoots and oscillations is selected. GA search employs *Integral of Time multiplied by Absolute Error* (ITAE) optimization technique. The performance index (objective function) is defined as

$$J = \sum_{i=1}^{N}\int_0^{\infty} t_i \left|\Delta\omega_i - \Delta\omega_1\right| dt \qquad (16)$$

Where $\Delta\omega_i$ = speed deviation of machine *I*; $\Delta\omega_1$ = speed deviation of machine 1st

3.1 General Structure of GA

The sequential steps for searching optimal solution of Fuzzy PID based PSS parameters using GA is shown in Fig. 5.

Design Methodology

(1) An initial population of individuals is randomly generated.

(2) The optimization of Fuzzy PID based PSS parameters are done by evaluating performance index J.

(3) If the value of *J* obtained is minimum, then the optimum value of PSS parameters equal to those obtained in the current generation, otherwise go to step 4.

(4) Based on the fitness, some individuals will be selected to populate the next generation.

The selection is based on stochastic universal sampling method. Selected individuals will be then recombined through a crossover process by exchanging genetic information between the pairs of the individuals contained in the current population.

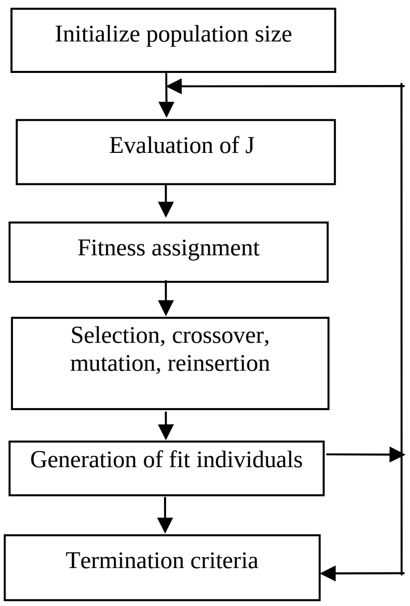

Fig. 5 Computational flow chart [14,15].

Table 1 MATLAB GA toolbox options.

PopulationSize	50
EliteCount	2
CrossoverFraction	0.9
MigrationInterval	20
MigrationFraction	0.2
Generation	100
StallGenLimit	50
StallTimeLimit	Inf
InitialPenalty	10
PenaltyFactor	100
Initial range	[-5;5]

After that, each individual in the population will be mutated with a given probability, through a random process of replacing one allele with another to produce a new genetic structure.

The GA stops when a pre-defined maximum number of generations are achieved. The GA also stops when the value returned by the objective function, being below a threshold, remains constant for a number of iterations.

The GA parameters used in this study are shown in Table 1.

4. Results and Discussion

To evaluate the effectiveness of the proposed stabilizer to improve the stability of power system, a simple two-area power system is studied [1]. Fig. 6 shows a simple two-area system. The nominal operating conditions and system parameters are given in Appendix [1]. A multimachine power system with synchronous generator provided with excitation system and governor system is considered. The power system dynamic performance of the proposed stabilizer was examined under small signal perturbation and large signal perturbation. The performance of the GAFPID based PSS is compared with three PSS that are the same setting for all machines. Three PSS are multiband PSS and the two conventional PSS whose parameters were optimized using phase compensation technique, i.e., w delta PSS and Pa delta PSS [1].

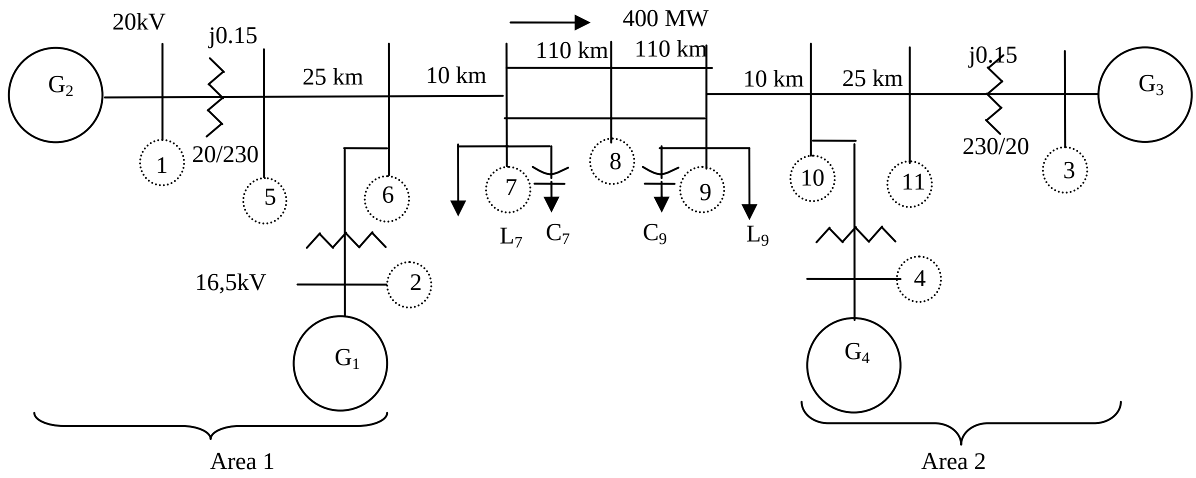

Fig. 6 A simple two-area system.

Without power system stabilizer, the system damping is poor and the system exhibits highly oscillatory response [1-4]. It is therefore necessary to install PSS to improve the dynamic performance.

A small perturbation 12-cycle pulse of 5% magnituda at the voltage reference of machine 1 and a large perturbation 8-cycles, three-phase fault with line outage are applied at nominal operating condition. The dynamic responses of machine all PSS are compared.

The corvergence rate of the fitness value J is shown in Fig. 7. The following solution with Genetic Algorithm fuzzy PID based PSS (GAFPID PSS) with minimum index performance is selected for the control purpose that is shown in Table 2.

4.1 Small Signal Perturbation Test

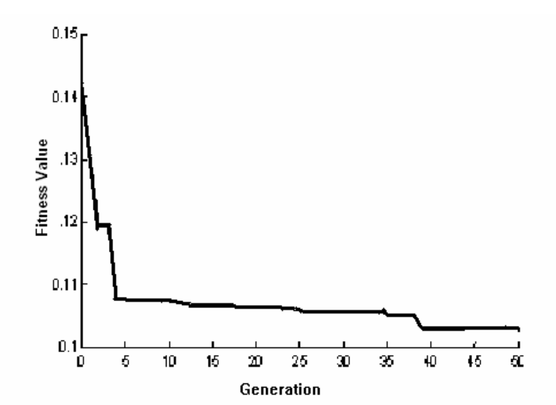

Fig. 7 Variation of the fitness value J.

Table 2 Optimization results.

L	Kp	K_i	K_d	K_{upi}	K_{ud}	T (fixed)
1.9	0.3217	0.3957	-2.8062	3.7388	-2.2205	0.1

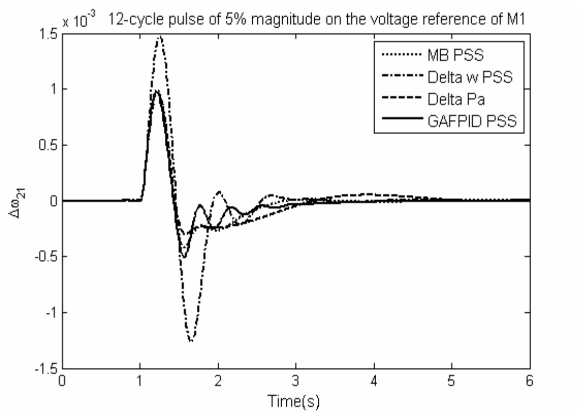

Fig. 8 Dynamic response for Δω21 for small perturbation with nominal load.

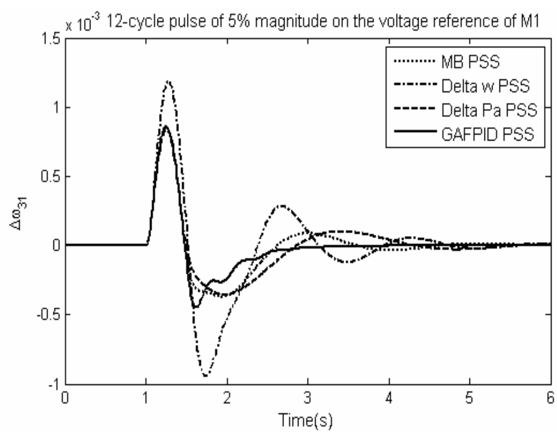

Fig 9 Dynamic response for Δω31 for small perturbation with nominal load.

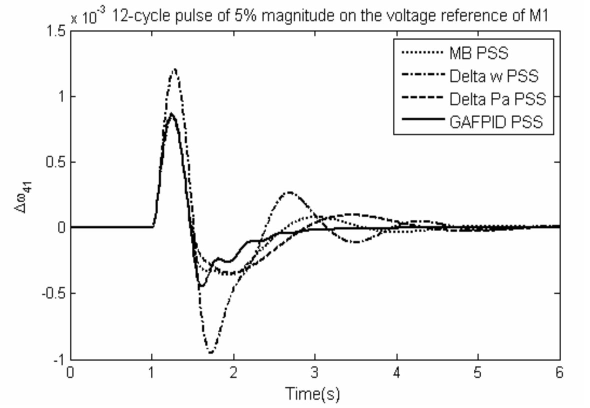

Fig 10 Dynamic response for Δω41 for small perturbbation with nominal load.

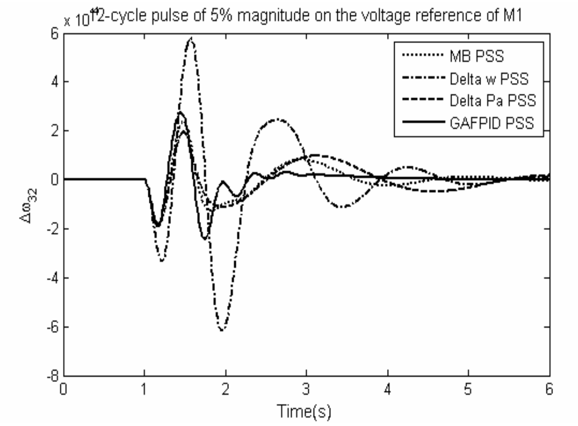

Fig. 11 Dynamic response for $\Delta\omega_{32}$ for small perturbbation with nominal load.

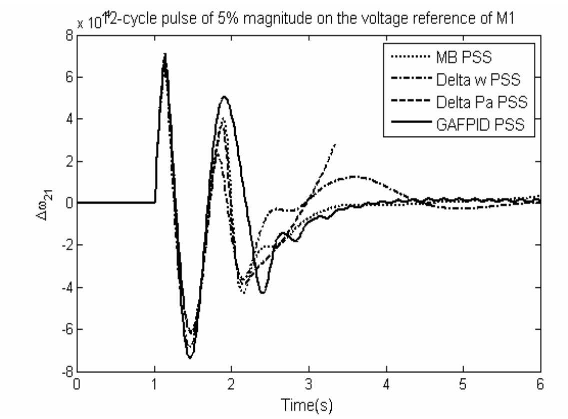

Fig. 12 Dynamic response for Δω21 for large perturbbation with nominal load.

A small perturbation 12-cycle pulse of 5% magnituda at the voltage reference of machine 1 was applied at nominal loading condition. The dynamic responses of GAFPID-PSS are compared with the three PSS. Figs. 8-10 show that the GAFPID-PSS stabilizer has lower peak over-shoots and damps out low frequency oscillations very quickly as compare to other PSS.

4.2 Large Signal Perturbation Test

A large perturbation 8-cycles, three-phase fault with line outage are applied at nominal operating condi-

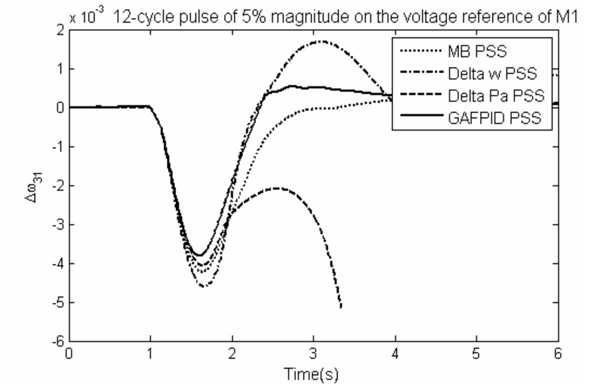

Fig. 13 Dynamic response for Δω31 for large perturbbation with nominal load.

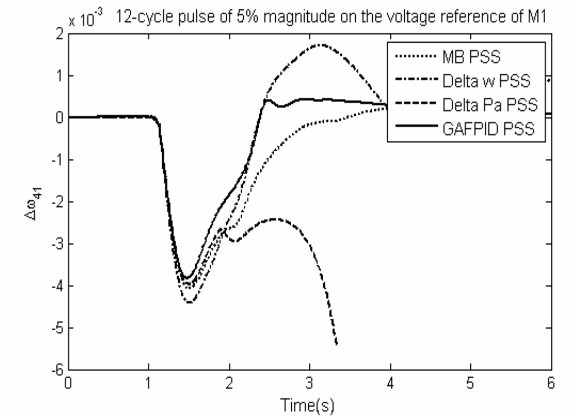

Fig. 14 Dynamic response for Δω41 for large perturbbation with nominal load.

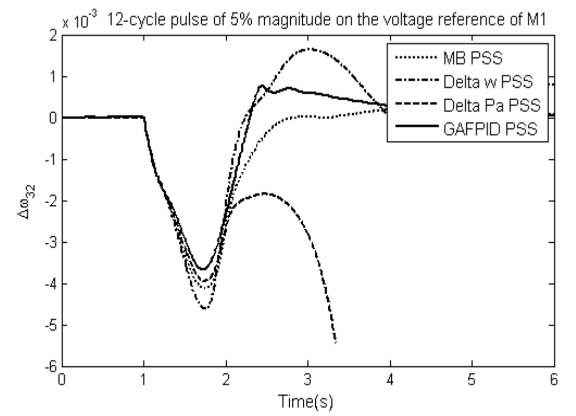

Fig. 15 Dynamic response for Δω32 for large perturbbation with nominal load.

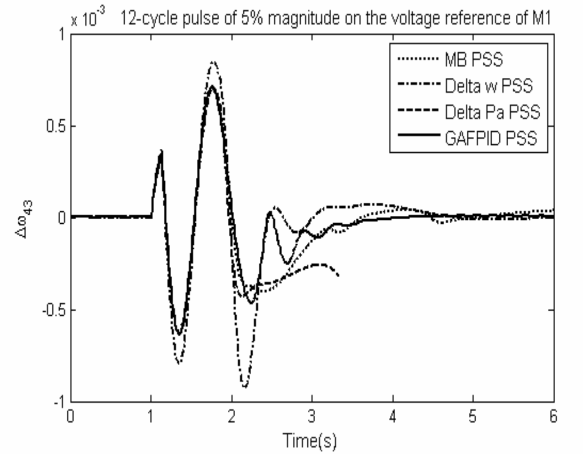

Fig. 16 Dynamic response for $\Delta\omega_{43}$ for large perturbbation with nominal load.

tion. Response to a three-phase fault for nominal loading condition are shown in Figs. 12 - 15. All figures show that the GAFPID-PSS has lower peak overshoots and damps out low frequency oscillations very quickly as compare to other PSS.

5. Conclusions

In this paper, a new technique the stabilization of power system and a different approach for designing a power system stabilizer are presented by using a GAFPID stabilizer. GA has been employed to perform the function of a GAFPID based PSS to improve the stability and dynamic performance of the power system. Computer simulation studies descryibed in the paper show that the performance of the GAFPID based PSS can provide very good performance.

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Appendix

Nominal System Parameters

The nominal parameters and operating conditions of the system are given below. All data are in per unit, except that H and the time constants are in seconds.

The system consists of two similar areas connected by a weak tie. Each area consists of two coupled units, each having a rating of 900 MVA and 20 kV. The generator parameters in per unit pu the rated MVA and kV base are as follows:

$$X_d = 1.8,\ X_q = 1.7,\ X_l = 0.2,\ X_d^{'} = 0.3,\ X_q^{'} = 0.55,$$

$$X_d^{''} = 0.25,\ X_q^{''} = 0.25,\ R_a = 0.0025\ T_{d0}^{'} = 8.0\ s,$$

$$T_{q0}^{'} = 0.4\ s,\ T_{d0}^{''} = 0.03\ s,\ T_{q0}^{''} = 0.05\ s,\ A_{sat} = 0.015$$

$B_{sat} = 9.6$; $\psi_{TI} = 0.9$;H = 6.5 (for G_1 and G_2); H = 6.175 (for G_3 and G_4); D = 0

Each step-up transformator has an impedance of 0 + j0.15 per unit on 900 MVA and 20/230 kV base, and has an off-nominal ratio of 1.0.